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Quantitative assessment of the motion of the lumbar spine in the low back pain population and the effect of different spinal pathologies on this motion

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Abstract There are few objective means by which disability caused by low back pain (LBP) can be quantified. The purpose of this study was to investigate the usefulness of motion measurements in the assessment of LBP. The motion characteristics of 138 LBP subjects were investigated, and the data compared with a previously published database of normal subjects. Values of range of motion and angular velocity were obtained for all subjects in each plane of motion. Analysis of these motion characteristics demonstrated significant differences ($P < 0.0001$) between the two populations; however both populations demonstrated considerable intersubject variation. Multiple regression analysis revealed that some of the variance in the LBP population was attributable to the underlying diagnosis. Patients with a spondylolisthesis tended to be hypermobile whilst those with spinal stenosis, disc prolapse or degenerative disc disease tended to be hypomobile. All diagnostic groups showed impairments in their velocity characteristics.

Key words Lumbar spine · Spinal motion · Normal population · Low back pain population · Diagnosis

Introduction

It is estimated that 50–80% of the population will experience some form of disabling low back pain (LBP) at some point in their lives [29], with the prevalence of LBP in the UK lying between 12 and 35% [15]. The National Back Pain Association [30] estimated that £5 billion (ca. $8 billion) is lost each year in the UK as a result of lost output from LBP, with 93 million certified days of sickness absence in 1992/3 as a result of LBP. This results in a yearly treatment bill of over £480 million (ca. $768 million) to the National Health Service.

The medical management of LBP patients is based upon clinical history and physical findings, and the measurement of motion forms a fundamental component of this examination. The measurement of motion has the advantage of being more objective and quantifiable than the assessment of subjective measures such as pain [21]. Panjabi et al. [31] postulated that abnormal spinal mechanics would be associated with abnormal spinal motion. However, to designate a motion as abnormal presupposes a knowledge of what is normal. Recent studies have developed comprehensive databases of normal lumbar spine motion [7, 24]. Unlike previous investigations of normal spinal motion [18, 28], they provide angular values of motion in each plane of motion.

Measurements of trunk range of motion (ROM) have frequently been used to make diagnostic, prognostic, and therapeutic decisions [8, 14, 27]. Gianturco [9], using a planar X-ray technique, was the first to note that the motion of LBP subjects deviated from the normal pattern of motion. Pearcy [32] expanded upon this technique, developing the biplanar radiography method for assessing intersegmental motion. However, there are limitations to its usage in routine investigations, not least its cost and complexity. In 1984 Mayer et al. [22] used the double inclinometric method to identify differences in the ROM of normal and LBP subjects. The usefulness of such measurements was disputed by Bogduk and Twomey [4], who

concluded that they provide only a non-specific index of spinal function.

In clinical practice it is often the observation of how the subjects move, as opposed to how far they move, that is of interest. A number of studies have confirmed the importance of velocity measurement, albeit in combination with clinical observation, to the assessment of LBP impairment [1, 16, 19, 20, 26]. More recent investigations stressed the relevance of higher order derivatives of motion (i.e. velocity and acceleration), and presented complex motion models to assist in discriminating between normal subjects and different diagnostic categories of LBP subjects [2].

Overall, it appears that an examination of the dynamic characteristics of motion would be of benefit. Preliminary investigations into dynamic motion in a small sample (20 subjects) of the LBP population support this argument [23]. However, as a result of the small population size in this previous study, the influence of diagnosis on presenting motion was not considered. The dynamic motion characteristics of the normal population have been investigated in depth and have shown an age and sex effect and great variation between subjects [24]. Therefore, the aim of this paper was to investigate the dynamic motion characteristics of the LBP population, and to investigate the relationship between underlying pathology and presenting motion characteristics using a non-invasive technique.

Materials and methods

Study population

Over a 2-year period, 138 subjects (76 male, 62 female) presenting to the hospital's outpatient clinic with LBP were recruited into this study. From radiographic and clinical findings the LBP patients were subdivided into one of the following diagnostic groups by an orthopaedic consultant blind to the results of the motion analysis:

1. Disc prolapse (DP): patients presenting with classical radiculopathy and evidence of disc prolapse at the appropriate level on MRI scan

2. Degenerative disc disease (DDD): patients presenting with LBP with or without non-radicular leg pain, in association with loss of disc height on plain radiology, or reduction in the disc water signal on T2-weighted MRI scans

3. Spondylolisthesis: patients presenting with LBP with or without radicular leg pain in association with an isthmic or degenerative cause with a 25% slip or more

4. Stenosis: patients presenting with LBP with neurogenic claudication in association with evidence of spinal canal stenosis on CT scan

5. Non-specific LBP (NSLBP): patients presenting with LBP without radicular leg pain and without clinical or radiological features of lumbar spine pathology

These subjects were compared with a previously generated database of normal motion characteristics obtained from 203 normal subjects (103 male and 100 female). Details of the numbers and mean age in each group are shown in Table 1.

Table 1 Classification of low back pain (LBP) subjects based on underlying pathology (*NSLBP* non-specific low back pain, *DP* disc prolapse, *DDD* degenerative disc disease)

Diagnostic group	No. of LBP subjects	Age (mean ± SD)
Normal	203	39.8 ± 13.1
NSLBP	25	41.4 ± 13.4
DP	33	35.2 ± 8.5
DDD	57[a]	51.1 ± 11.0
Spondylolisthesis	12	37.8 ± 15.9
Stenosis	11	54.9 ± 14.3

[a] Twenty-four percent of the DDD subjects presented with radicular pain

Measurement equipment

All measurements were made using a computerised triaxial potentiometric analysis system (CA-6000 Spinal Motion Analyser, OSI, California, USA). This system consists of a link arm incorporating six high-precision potentiometers connected through several bars: three in the sagittal plane to allow the determination of antero-posterior (A-P) flexion-extension; two in the frontal plane to detect lateral bending; and one in the transverse plane to detect rotation. The link arm is attached to the subject via two harnesses, one around the chest at the level of the thoracolumbar junction, and the other around the pelvis at the level of the posterior superior iliac spines (Fig. 1). Thus, the system measures the gross movement occurring between the thorax (below the level of T12) and the pelvis above the level of the lumbosacral joint. The precision and repeatability of this system have been previously described [24]. The

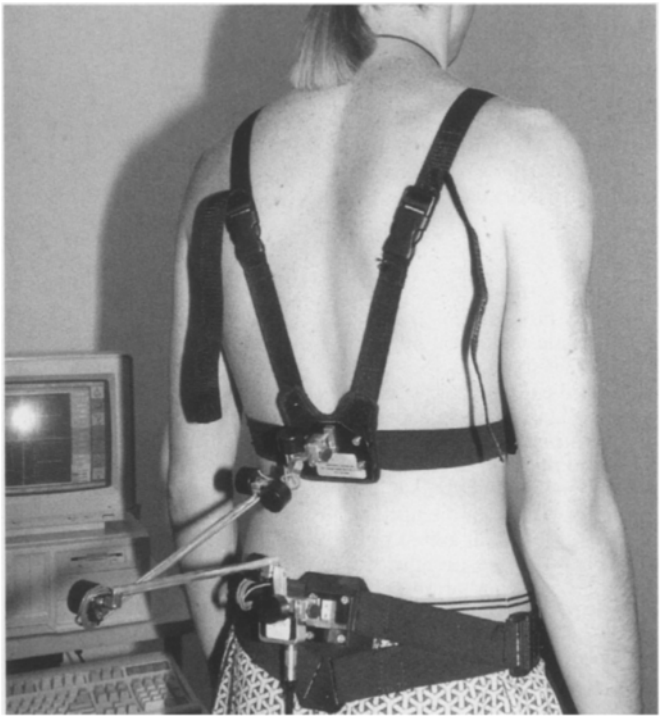

Fig. 1 Positioning of the link arm and harnesses on a subject

possibility of errors induced by movement of these harnesses and the overall test procedure were assessed in a repeatability study that investigated the intra- and interobserver errors [24]. The results of this study showed that observer errors were minimal (interobserver repeatability mean difference of 2.4° ± 3.3° ROM flexion). It was noted that during the test procedure the movement of harness systems over the skin surface was limited, at < 0.5 mm, and the repeatability of the system was noted to be no different when a skin fixation system was used [36]. The equipment itself does not impede the subject's movement. As the subject moves, the resistance of the potentiometers changes. This change in resistance is sampled at a frequency of 10 Hz by an analogue-to-digital converter (a sample rate of 10 Hz is adequate for the assessment of simple planar movements). The raw data is interpreted through a personal computer and displayed as a curve of angle against time. A QBasic program was then written to calculate the velocity characteristics.

Test procedure

This study was approved by the local ethical committee, and all subjects gave informed written consent. Before testing, subjects were asked to record their resting pain levels on a visual analogue pain scale. Testing was performed with the subject minimally clothed and barefoot. Each subject was asked to stand looking straight ahead with the feet 0.2 m apart, and the potentiometers were set to this resting posture. Prior to recording, each subject performed a practice movement to ensure comprehension of the test procedure. No further warm-up procedure was performed, since many LBP subjects are not able to tolerate both a warm-up procedure and the test, and the work of Dvorák et al. [7] did not find conclusive evidence that stretching prior to measuring increased ROM. After the practice movement, each subject performed a series of three unconstrained movements, at their preferred pace, in each plane of motion, within their limits. Preferred pace was chosen, as opposed to maximal performance. Preferred motion characteristics have been shown by McIntyre et al. [25] to be equally consistent in both normal and LBP subjects, and are believed to portray a more realistic measure of a subject's functional ability, since during daily function people rarely perform at their optimal level. Tests of physical performance rely on the subject's co-operation and motivation to perform the test; these parameters were, however, not assessed. The test order was the same for each subject, namely a rotation arc, followed by a lateral bending arc and finally a flexion-extension arc.

Analysis

Each test procedure is displayed graphically as a curve of angle against time. A typical output curve from a flexion-extension test in a normal subject is shown in Fig. 2. The initial step in the analysis was to calculate the maximum ROM that could be determined from the apex of each curve. The output curves were then divided into their principal components, i.e. left and right rotation and lateral bending respectively, and flexion and extension. In turn, each component was subdivided into two phases, a descent phase, taken as the interval from the upright position to the 90% point of maximum ROM, and an ascent phase, taken as the 90% point of maximum ROM to the upright position. The apex of each curve was considered to be a turning phase and was ignored. For each phase the mean velocity was calculated.

Statistical analysis

The statistical analysis was performed using the statistical package Stata (Stata Corporation, Texas) on a personal computer. The motion characteristics of the normal subjects and the LBP subjects as a whole were compared using the Student *t*-test, since using the Shapiro-Francia W^1 test the distribution of the data was found to be normal. However, to consider the effect of diagnosis on motion, an analysis of variance (ANOVA) was performed and multiple regression models were generated to compare each LBP diagnostic group with the normal population (age and sex differences between groups were accounted for). The possibility of any interaction effects for age, sex and classification group were also investigated.

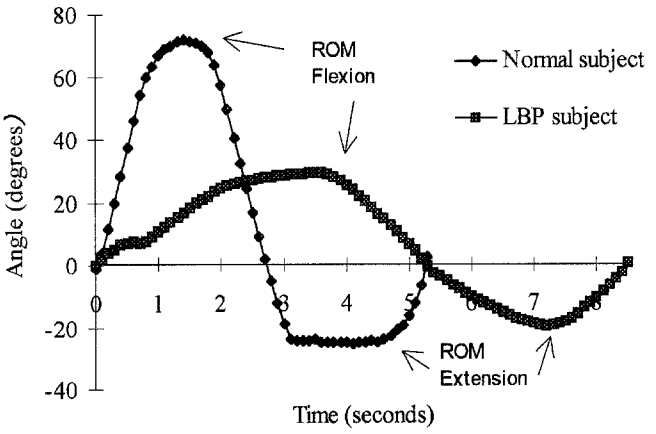

Fig. 2 Differences in the shape of the output curves generated by a normal and an acute low back pain (LBP) subject during an antero-posterior flexion-extension test (*ROM* range of motion)

Results

On initial inspection of the curves of motion from randomly selected subjects, there appeared qualitatively to be two distinctive shapes of output curve generated during an A-P flexion-extension test (Fig. 2). The typical curve generated by normal subjects resembled an asymmetric sinusoidal curve, with the asymmetry being a result of subjects demonstrating a greater range of flexion than extension. The output curve of normal subjects tends to demonstrate a smooth, controlled motion, whilst the typical output curve from a subject with acute LBP shows a marked limitation in ROM and a staged descent into flexion and extension, with a rapid ascent from the position of maximum ROM. This suggests that LBP sufferers have difficulty moving and are unsure of how fast or how far they can move, possibly due to either pain or fear of pain. The mean resting pain score (as measured on the visual analogue scale) of the LBP subjects was 5.1 ± 2.8. Visual analogue pain scale ratings were found to be significantly correlated with motion ($P < 0.05$), but the ratings of pain were only able to account for a very small percentage (less than 10%) of the variability seen. No clear differences were seen in the shapes of the rotation and lateral bending curves, although patients with back pain appeared to move somewhat slower than normals.

Range of motion data

Analysis of the ROM data revealed that LBP subjects demonstrated a reduction in ROM compared with controls in all planes of motion, as can be seen from Fig. 3. These differences were all significant, with $P < 0.0001$. However, the standard deviations are relatively large, and dotplots of the data were generated to examine the findings in more depth (Fig. 4). These dotplots revealed that there is considerable overlap between the groups in all planes of motion. This suggests that although the mean behaviour of LBP sufferers differs from that of normals individual measurements of motion characteristics may not be very sensitive in categorising individual patients, limiting the routine clinical usefulness of these measurements on individual patients for diagnostic purposes.

It was thought that some of the variation seen in the LBP population could be due to the underlying pathology, and so the effect of diagnosis on motion was investigated, and the dynamic output curves of the five different diagnostic groups are compared with normals in Fig. 5. Considering initially the classification system based upon underlying pathology, significant differences were seen between diagnostic groups (Fig. 6, Table 2). These differences accounted for 12–24% of the variability seen in the data, depending on the plane of motion under examination. Subjects diagnosed as having stenosis, DDD or DP showed significant differences from the normal population in terms of ROM of flexion and extension ($P < 0.05$), whereas those having a diagnosis of NSLBP or spondylolisthesis did not. Instead, subjects with either NSLBP or a spondylolisthesis showed a trend of greater ROM than the normal population. When the other planes of motion were investigated, all diagnostic groups were significantly

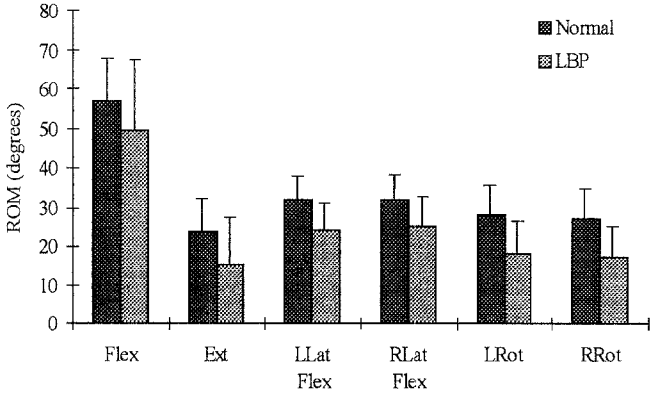

Fig. 3 Mean ROM values for normal and LBP subjects, with standard deviations represented by error bars (*Flex* flexion, *Ext* extension, *LLat* left lateral bending, *RLat* right lateral bending, *LRot* left rotation, *RRot* right rotation)

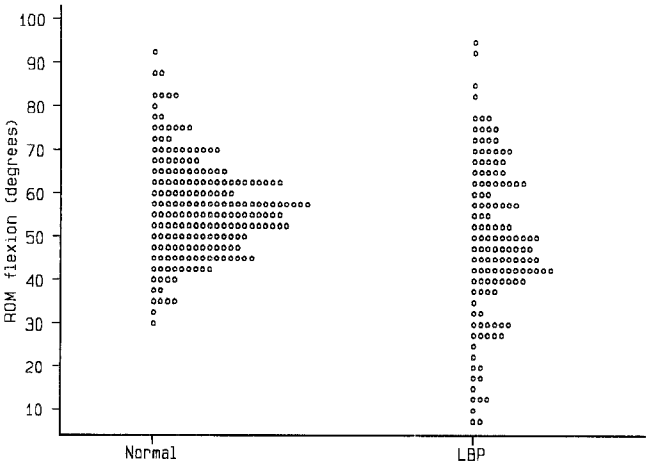

Fig. 4 Scatterplot of ROM flexion in each population demonstrates that both the normal and LBP populations described have a normal distribution. However, it can be seen from this plot that there is considerable variability in values of ROM flexion in both populations, such that although statistically there are significant differences between the two groups, clinically it would be difficult to use measures of ROM to differentiate between a normal and an LBP subject

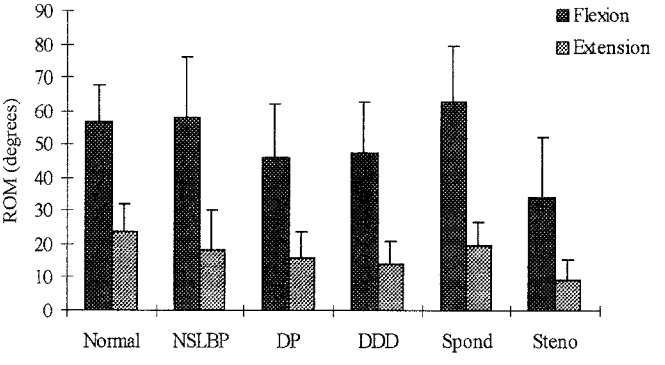

Fig. 5 The mean ROM flexion (degrees) in each diagnostic group (*NSLBP* non-specific low back pain, *DP* disc prolapse, *DDD* degenerative disc disease, *Spond* spondylolisthesis, *Steno* stenosis)

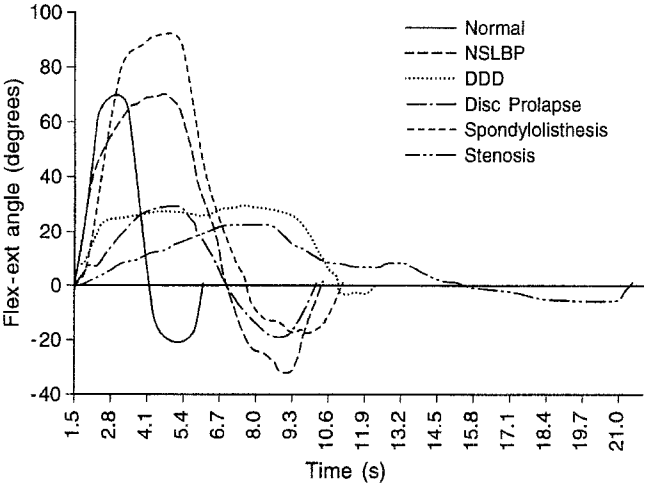

Fig. 6 Typical dynamic output curves generated by subjects with different LBP pathology

Table 2 Range of motion (ROM) values (degrees) for each diagnostic group in each plane of motion, presented as mean ± SD (*Spond* spondylolisthesis)

	n	Flexion	Extension	Left lateral bending	Right lateral bending	Left rotation	Right rotation
Normal	203	56.7 ± 11.2	23.8 ± 8.4	31.8 ± 6.3	32.0 ± 6.5	27.6 ± 8.1	27.0 ± 7.5
NSLBP	25	58.1 ± 18.0	18.2 ± 12.3	24.6 ± 7.7	27.0 ± 8.3	19.4 ± 10.5	18.9 ± 10.1
DP	33	46.0 ± 16.6	15.8 ± 8.6	26.0 ± 6.8	26.7 ± 7.2	18.6 ± 8.3	17.7 ± 7.6
DDD	57	47.5 ± 15.6	14.0 ± 7.7	23.7 ± 6.0	23.0 ± 6.7	17.5 ± 7.2	16.4 ± 6.7
Spond	12	62.4 ± 17.7	19.6 ± 7.1	25.0 ± 9.1	27.3 ± 8.2	18.4 ± 9.6	17.1 ± 8.5
Stenosis	11	33.8 ± 18.5	9.3 ± 5.8	19.7 ± 7.8	21.3 ± 11.0	15.4 ± 10.4	15.4 ± 8.7

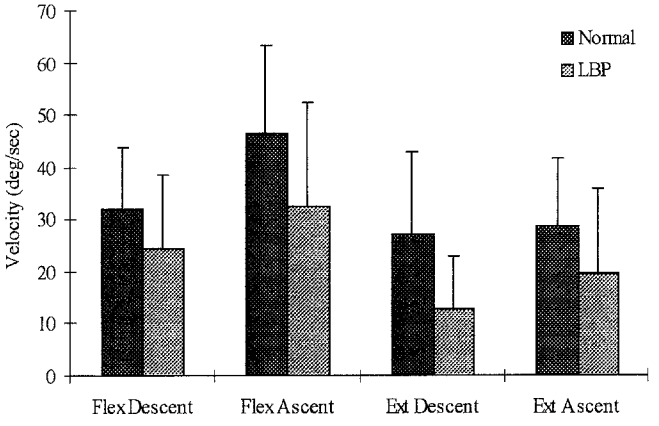

Fig. 7 Mean velocity characteristics of each phase of flexion and extension in normal and LBP subjects

less flexible than the normal population in both lateral bending ($P < 0.01$) and rotation ($P < 0.0001$). The presence of any interaction effects between age, sex and diagnostic group were examined, but no significant interactions were identified.

Velocity characteristics

When the mean velocity characteristics of the normal and LBP population were compared, highly significant differences between the two groups were seen in all planes and all phases of motion ($P < 0.0001$). Figure 7 illustrates the mean flexion descent velocity results; details of mean velocity characteristics for the other phases of A-P flexion-extension, lateral bending and rotation are tabulated in Tables 3, 4 and 5.

The effects of diagnosis on mean velocity characteristics revealed that in rotation and lateral bending, all diagnostic groups were significantly different from normal ($P < 0.0001$) in all phases (Tables 2, 3). However, in A-P flexion-extension, all groups except for the spondylolisthesis group showed significant differences from normal ($P < 0.0001$; Fig. 8). The spondylolisthesis group differed

Table 3 Motion velocity characteristics (degree/second) during an A-P flexion-extension test (mean ± SD)

	n	Flexion descent velocity (°/s)	Flexion ascent velocity (°/s)	Extension descent velocity (°/s)	Extension ascent velocity (°/s)
Normal	203	31.9 ± 12.5	46.5 ± 17.4	27.0 ± 16.7	28.6 ± 13.6
NSLBP	25	24.4 ± 13.6	32.5 ± 19.8	12.8 ± 10.3	19.7 ± 15.5
DP	33	17.1 ± 12.0	17.1 ± 12.0	11.6 ± 10.0	16.4 ± 11.9
DDD	57	18.1 ± 10.2	25.4 ± 14.0	11.2 ± 8.3	16.8 ± 12.4
Spondylolisthesis	12	25.1 ± 12.6	32.4 ± 15.0	13.7 ± 6.5	27.9 ± 13.7
Stenosis	11	10.5 ± 8.1	15.3 ± 14.5	6.0 ± 4.5	11.3 ± 12.1

Table 4 Mean velocity characteristics (degree/second) during a lateral bending test (mean ± SD)

	n	Left lateral bending descent	Left lateral bending ascent	Right lateral bending descent	Right lateral bending ascent
Normal	203	24.6 ± 9.7	41.7 ± 12.0	36.4 ± 15.7	40.8 ± 13.4
LBP	138	14.4 ± 8.0	25.5 ± 12.4	20.0 ± 12.2	24.1 ± 13.2
NSLBP	25	15.5 ± 8.0	26.5 ± 12.7	21.6 ± 11.2	24.4 ± 12.5
DP	33	16.4 ± 8.9	28.6 ± 13.6	21.1 ± 15.0	28.7 ± 16.0
DDD	57	13.8 ± 6.7	25.0 ± 10.7	20.0 ± 11.1	23.4 ± 10.4
Spondylolisthesis	12	15.4 ± 7.8	25.2 ± 9.7	21.0 ± 9.2	24.2 ± 9.4
Stenosis	11	10.5 ± 4.6	21.1 ± 10.7	15.0 ± 9.8	17.3 ± 9.2

Table 5 Mean velocity characteristics (degree/second) during a rotation test (mean ± SD)

	n	Left Rotation Descent	Left Rotation Ascent	Right Rotation Descent	Right Rotation Ascent
Normal	203	26.6 ± 13.3	29.0 ± 15.7	36.9 ± 19.9	25.0 ± 12.1
LBP	138	11.9 ± 8.5	14.8 ± 10.3	15.1 ± 11.7	13.3 ± 8.6
NSLBP	25	12.0 ± 9.3	16.7 ± 14.4	16.6 ± 12.2	16.5 ± 11.9
DP	33	12.9 ± 9.6	15.9 ± 11.3	17.4 ± 16.9	13.4 ± 9.9
DDD	57	11.1 ± 6.7	14.1 ± 8.2	14.3 ± 8.8	12.5 ± 5.9
Spondylolisthesis	12	14.7 ± 12.7	14.3 ± 8.2	13.5 ± 7.3	13.3 ± 8.2
Stenosis	11	9.1 ± 5.1	11.4 ± 8.5	11.2 ± 7.1	9.6 ± 6.8

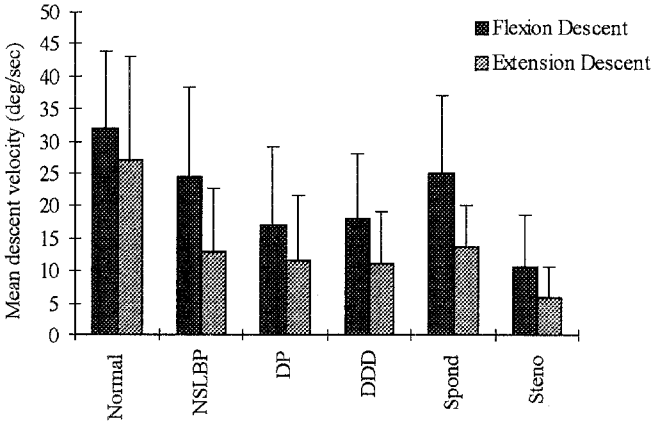

Fig. 8 Mean flexion descent characteristics in each diagnostic group

from normal only during mean flexion descent, and ascent ($P < 0.05$). These diagnostic differences accounted for 21–35% of the variability seen in the data, depending on the plane and phase of motion.

Discussion

The mobility of the vertebral column has been a focus for study by researchers for over a century, and controversy still exists as to the best method of assessment. Numerous techniques for assessing spinal ROM have been documented in the literature [2, 10, 12, 13, 17, 28, 32, 35, 37]; however, there are major limitations with the majority of these techniques. The primary limitation relates to the fact that most of these methods are static in nature and are capable of measuring in only one plane of motion.

This study has investigated the dynamic motion characteristics of the lumbar spine using a computerised potentiometric analysis system in all planes of motion. The results of this work, as reflected in the output curves generated by the apparatus, have shown that there are characteristic differences in the motion characteristics of the normal and LBP populations. In clinical practice, subjects with LBP often exhibit slow, guarded motion, in contrast to normal subjects, who move smoothly and with ease.

Quantitative assessment of the output curves has shown that there are significant differences in the flexibility and velocity characteristics of the normal and LBP population. LBP subjects demonstrate a restriction in ROM, and an impairment in mean velocity. The findings relate well to what is seen in clinical practice, and are in agreement with previous findings [19, 22]. The causes of these differences in motion are not known, but are thought to represent either changes in the mechanics of the spine or a response to pain or fear of pain. Dvorák et al. [6] noted a hypomobility in the LBP population, but attributed this to the fact that the LBP population was older than the normal population. Gomez et al. [11] felt that dynamic movements of the trunk resulted from a complex of neuromuscular synergistic co-ordination, motivation, skill, physiologic strength and flexibility, and metabolic support. Therefore, the speed at which a subject moves is reflective of all these factors and should be sensitive to any dysfunction in one or more of these factors, although it will not be specific as to the cause of the impairment. Marras and Wongsam [19] postulated that LBP subjects tended to exhibit a limited ROM in an attempt to minimise the static load upon the spine, and that they demonstrated a reduced velocity in an attempt to decrease the acceleration component of the trunk, and thus the resulting forces acting on the spine.

Preliminary analysis of the motion data of the normal and LBP populations had suggested that velocity measurements may be more sensitive measures of impairment than ROM [23]. There was no evidence of this when a more detailed analysis was performed on a larger sample of the two populations. It is also interesting to note that subjects tend to exhibit greater velocities when moving to the right. It is felt that this phenomenon is a reflection of the test procedure. During the test procedure subjects move from the stationary position to the left, and from this position to the right without resting again in the upright position. Moving to the right they do not have to overcome inertia and have already generated some momentum as they return from the left position.

Caution, however, is required when interpreting the results of this study, due to the large variation seen in both populations. Patients with LBP exhibit a wide range of motion characteristics. Although the mean behaviour of the LBP population as a group differs from the normal population, it is difficult to distinguish individual patients from normals with any degree of sensitivity. This finding,

therefore, limits the diagnostic usefulness of these measurements.

The variation seen in the LBP population may be the result of classifying a variety of spinal disorders, at different stages in the disease process, as one group. The effects of diagnosis on motion were therefore investigated. Statistical analysis revealed that diagnosis did have an influence on spinal motion, but this varied with each different parameter of motion and only accounted for a small proportion of the variation seen. ROM appeared to be a more sensitive parameter in detecting differences between normal subjects and pathologic diagnostic groups, with patients suffering from spinal stenosis, disc prolapse, and degenerative disc disease showing the most marked differences from the normal. Subjects with a diagnosis of non-specific back pain showed very little deviation from the normal. However, subjects with a diagnosis of spondylolisthesis demonstrated a non-significant trend to hypermobility, a feature previously noted by Bailey in 1947 [3]. In contrast, Pearcy and Shepherd's [33] investigations into subjects with spondylolisthesis demonstrated a restriction in motion at all intervertebral levels during flexion using biplanar radiography, although it was noted that the resultant movement was dependent on the grade of the spondylolisthesis and the severity of the symptoms. This suggests that future studies into this sub-division of the LBP population should specify the grade of the spondylolisthesis and the severity of the resultant symptoms. These results contrast with those of the study by Dvorák et al. [6], which noted that flexion-extension roentgenograms were unable to distinguish between four pathologic patient groups. A recent study by Marras et al. [20], however, proposed that motion models could be used to diagnose low back disorders, but further validation of these models is required. In this model, complex non-linear boundaries are generated between diagnostic groups which suggests that, as has been seen in this study, there is great variability within diagnostic groups.

The measurement technique itself has been shown to be reproducible. The intersubject variation in each population and each diagnostic group may limit the usefulness of a single measurement on a patient, but it is precise enough to be able to detect relatively small changes in serial measurements. Therefore, it is felt that the real benefit of these measurements will be in evaluating the outcome of different interventions in different diagnostic groups.

Conclusion

This study has shown that there are significant differences between the motion characteristics of the normal and LBP populations. However, due to the heterogeneous nature of both populations, there is great variability within the two groups, limiting the clinical usefulness of these measurements in differentiating between a normal and an LBP subject. Some of the variability seen in the LBP population is attributable to different pathological processes. ROM appeared to be a more sensitive parameter than velocity in detecting differences between diagnostic groups, and it appeared that patients suffering from spinal stenosis, disc prolapse and DDD showed the most marked differences from the normal population. This finding is of interest, since it is these categories of back pain patients that tend to require surgery. However, clinical diagnosis cannot be based on measurements of motion alone. This study suggests that motion analysis may provide useful surgical indicators and offer a reliable outcome measure in surgical evaluation. This, however, requires further investigation.

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